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DETERMINATION OF THE RADIANTS, ALTITUDES AND VELOCITIES OF METEORS OBSERVED IN KIEV IN 1959

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ABSTRACT. Data are presented on photographic observations of meteors at the Kiev State University Astronomical Observatory in 1959. A brief description is given of the method of analyzing photographs of reference meteors for determining their radiants, altitudes, velocities and deceleration. The results are given for measurements of eight reference meteors.

In 1959, at two field stations of the Kiev University Astronomical Observatory in the villages of Lesnika and Tripol'ye, systematic photographic observations of meteors were carried out in accordance with the IGY and IGC program (ref. 1). /25*

Photographic scanning was conducted by the AS-11 meteor patrols (ref. 1) on all clear, moonless nights, partially on Panchromatic aerial photofilm with a sensitivity of $Sd_{0.85+d0}$=1000-1300 GOST (Goverment Standard) units and partially on Isopanchromatic aerial photofilm type DK.

Table 1 presents data on the duration of observations and the number of meteors photographed at each station individually and common to both stations.

TABLE 1.

Number	Observations: Point A Lesnika	Observations: Point B Tripol'ye	Number common to both points
of observation nights	106	87	72
of hrs of observation	422	389	283
of meteors photographed	54	66	8

The meteor negatives were measured on the KIM-3 coordinating and measuring apparatus by two co-workers, one of whom made two aims each, both directly and in reverse position of the reversible lens while the other made one control measurement of each point. The picture was oriented such that the x-axis was directed along the image of the meteor. We measured the Y images of the meteor, the XY ends of the intervals (marks) in the images of the reference stars, the XY ends of the intervals of the meteor image on the photograph made through an obturator and the XY intersections of the reference stars with a meteor trail.

* Numbers in the margin indicate original pagination in the foreign text.

[1] Kiev University Astronomical Observatory.

The mean positions of the reference stars were extracted from the AK_2 or BOSS catalogs with an accuracy to 1" and were thus related to the 1950.0 equinox.

The points of intersection of the meteor with large circles passing through two marks at the reference stars on different sides of the meteor were selected to serve in the capacity of base points. Their coordinates were selected by a method described by A. N. Deych (ref. 2). /26

Further handling of photography in both features corresponds to that used at the Odessa Astronomical Observatory (ref. 3), but each individual step more or less naturally differs from it. Therefore, formulas which we used in our processing are presented below.

In all computations we used the direction cosines of the radius-vectors of the base points in the coordinate system related to the observation point. The beginning of the coordinates of the system is at the center of the camera objective, the axis OZ is directed toward the target pole, OX to the point of intersection of the meridian with the equator, OY to the west point. An arbitrary point in the celestial sphere with coordinates $t\delta$ was determined by the unit vector with components

$$a=\cos\delta\cos t,\quad b=\cos\delta\sin t,\quad c=\sin\delta.$$

The direction cosines of the pole of the large circle (a_p, b_p, c_p) can be found from the condition of orthogonality of the unit vector directed toward the pole with all vectors of the base points

$$\left.\begin{array}{c}(a_{0i}, b_{0i}, c_{0i}):\\ a_p a_{0i} + b_p b_{0i} + c_p c_{0i} = 0,\\ i = 0,\ 1,\ 2, \ldots, n.\end{array}\right| \qquad (1)$$

To avoid losses in accuracy in calculation of divisors during solution of system (1) by the least squares method, we applied the following method. The coordinates of the pole of the large circle were determined; it was derived through the limiting reference points:

$$a_p^{(0)} = \frac{A_p}{\sqrt{A_p^2 + B_p^2 + C_p^2}};\quad b_p^{(0)} = \frac{B_p}{\sqrt{A_p^2 + B_p^2 + C_p^2}};\quad C_p^{(0)} = \frac{C_p}{\sqrt{A_p^2 + B_p^2 + C_p^2}},$$

where

$$A_p = b_{01}C_{0n} - b_{0n}C_{01};\qquad B_p = C_{01}a_{0n} - a_{01}C_{0n};\qquad C_p = a_{01}b_{0n} - a_{0n}b_{0}.$$

Then the $a_p^{(0)}$, $b_p^{(0)}$, $c_p^{(0)}$ which were obtained were refined.

Let the refined values of the polar coordinates be

$$a_p = a_p^{(0)} + \Delta a_p; \quad b_p = b_p^{(0)} + \Delta b_p; \quad c_p = c_p^{(0)} + \Delta c_p, \tag{2}$$

Then $\Delta a_p, \Delta b_p$ can be determined, solving by means of the least squares method with

$$\left(a_{0i} - \frac{a_p^{(0)}}{c_p^{(0)}} c_{0i}\right) \Delta a_p + \left(b_{0i} - \frac{b_p^{(0)}}{c_p^{(0)}} c_{0i}\right) \Delta b_p = -\sin R_{0i}^{(0)}, \tag{3}$$

where R_{0i} is the angle of inclination of the i-th reference point from the large circle with the pole $a_p^{(0)}$, $b_p^{(0)}$, $c_p^{(0)}$:

$$\sin R_{0i}^{(0)} = a_{0i} a_p^{(0)} + b_{0i} b_p^{(0)} + c_{0i} c_p^{(0)}. \tag{4}$$

we calculate Δc_p by the formula /27

$$\Delta c_p = -\frac{a_p^{(0)}}{c_p^{(0)}} \Delta a_p - \frac{b_p^{(0)}}{c_p^{(0)}} \Delta b_p. \tag{5}$$

The algorithm (2)-(4) is valid under conditions $\sin^2 R_{0i}^{(0)} \approx 0$. These formulas are suitable to use if $c_p^{(0)}$ from the three numbers $a_p^{(0)}, b_p^{(0)}, c_p^{(0)}$ is found to be the greatest in terms of absolute quantity; however, if some other number is greatest, in (3) and (5) it is then necessary to apply the cyclic transposition of variables such that in the denominators we find the greatest (in absolute quantity) of the direction cosines.

Having determined the corrections $\Delta a_p, \Delta b_p, \Delta c_p$, we find the polar coordinates (2) and inclination of the reference points $\sin R_{0i}$ from the refined large circle, substituting into (4) the direction cosines of the refined pole. Analysis of the quantities $\sin R_{0i}$ permits us to locate the reference points with wrong coordinates. Such points were eliminated and calculations (3)-(5) were repeated, while the corrections to the pole already corrected were sought. After determination of the coordinates of the poles of the large meteor circles corresponding to two photographs of the meteor obtained from different points, the direction cosines of the radiant were determined as coordinates of the pole of the large circle passing through the pole of the meteor circles on both photos

$$a_R = \frac{A_R}{\sin Q}, \quad b_R = \frac{B_R}{\sin Q}, \quad c_R = \frac{C_R}{\sin Q}, \tag{6}$$

where

$$A_R = b_{PA}c_{PB} - b_{PB}c_{PA}, \quad B_R = c_{PA}a_{PB} - c_{PB}a_{PA},$$
$$C_R = a_{PA}b_{PB} - a_{PB}b_{PA};$$

a_R, b_R, c_R are the direction cosines of the radiant; Q is the angle of convergence of the large meteor circles, while

$$\sin Q = \pm\sqrt{A_R^2 + B_R^2 + C_R^2}.$$

Whence the coordinates of the radiant

$$\delta_R = \arc\sin c_R,$$
$$t_R = \begin{cases} \operatorname{arc\,tan} \dfrac{b_R}{a_R} & \text{for } a_R > 0, \\ \operatorname{arc\,tan} \dfrac{b_R}{a_R} + 180^\circ & \text{for } a_R < 0. \end{cases} \tag{7}$$

Because formulas (6) and (7) give the coordinates of the radiant or anti-radiant as a function of the selection of the sign sin Q, it is necessary to verify that the point (a_R, b_R, c_R) lies on the horizon. This can be done by calculating the cosine of the zenith distance

$$\cos z_R = a_R \cos\varphi_A' + c_R \sin\varphi_A',$$

where φ_A' is the geocentric latitude of the point A. If it is found that $\cos z_R < 0$, the signs in a_R, b_R, c_R must be changed to the opposites.

To determine the velocities and decelerations we must know the angular distances of the ends of the intervals from any point to a meteor whose coordinates $\{a_0, b_0, c_0\}$ are known. One of the reference points may be selected in the capacity of the latter. The angles λ_{0i} of the remaining reference points are found from this basic one by conditions /28

$$\cos\lambda_{0i} = a_{0i}a_0 + b_{0i}b_0 + c_{0i}c_0. \tag{8}$$

Knowing that λ_{0i} and X_{0i} are the measured coordinates of the points, it is possible to determine the scale in the intervals between the reference points and then, having constructed a graph of the scale, we find that λ_j is the angular distances from the ends of the intervals to the basic reference point.

The linear distance from the point with the obturator apparatus to the basic point on the meteor was determined by the formula

$$r_0 = B_0 \frac{a_{PB}a + b_{PB}b + c_{PB}c}{a_{PB}a_0 + b_{PB}b_0 + c_{PB}c_0},$$

where B_0 is the length of the reference chord and a, b, c are the direction cosines of the reference chord in the system of point A.

The elongation of the basic reference point from the radiant was found from the relationship

$$\cos\psi_0 = a_R a_0 + b_R b_0 + c_R c_0.$$

The linear distance from the basic reference point at the meteor to the point at a distance from it at the angle λ_j is equal to

$$L_j = z_0 \frac{\sin\lambda_j}{\sin\psi_0 + \lambda_j}.$$

If ϱ_A (see figure) is the geocentric radius-vector of the point A; ϱ_j is the radius-vector of the point on the Earth's surface (in our case Earth is the Krasovskiy spheroid) to which the j-th point on the meteor is projected; $\bar{r}_0$ is /29 the topocentric radius-vector of the basic reference point on the meteor and $\bar{L}_j$ is the vector passing from the basic reference point to the arbitrary point on the meteor, the altitude of this point is obviously equal to

$$H_j = \sqrt{(\bar{\varrho}_A + \bar{r}_0 + \bar{L}_j)^2} - \varrho_j. \quad (8)$$

Considering that

$$\bar{\varrho}_A \bar{r}_0 = \varrho_A r_0 \cos z_0,$$

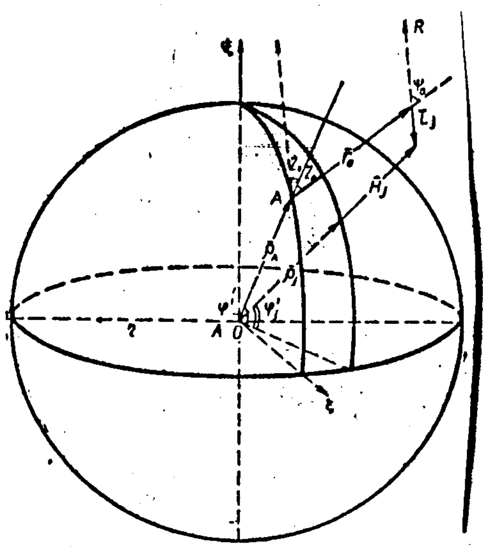
$$\varrho_A \bar{L}_j = \varrho_A L_j \cos z_R,$$

$$\bar{r}_0 \bar{L}_j = -r_0 L_j \cos\psi_0,$$

where z_0 is the zenith distance of the basic reference point on the meteor;

ψ_0 is the elongation of the basic reference point from the radiant; z_R is the zenith distance of the radiant, expression (8) is rewritten in the form

$$H_j = \varrho_A \left[\sqrt{1 + \left(\frac{r_0}{\varrho_A}\right)^2 + \left(\frac{L_j}{\varrho_A}\right)^2 + 2\left(\frac{r_0}{\varrho_A}\right)\cos z_0 - 2\left(\frac{L_j}{\varrho_A}\right)\cos z_R - 2\left(\frac{r_0 L_j}{\varrho_A^2}\right)\cos\psi_0} - \frac{\varrho_j}{\varrho_A} \right]. \qquad (9)$$



It is helpful to approximately extract the root in (9), having expanded it in series by the roots

$$\frac{r_0^n L_j^m}{\varrho_A^{n+m}},$$

and, rejecting series expansion of terms whose sum is less than 5 m, we obtain

$$H_j = h_0 + h_1 L_j + h_2 L_j^2 + \Delta\varrho_j,$$

Meteor No.	Date	Transit moment UT	Apparent Radiant		Corrected radiant		λ	No. of In-tervals
			t 1950.0	δ 1950.0	α 1950.0	δ 1950.0		
36	1959 II, 12	$22^h45^m58^s$	290°29	38°46	224°07	38°35	4°4	23
37	1959 III, 17	0 35 36	28 47	30 52	182 50	29 44	3,3	16
38	1959 IV 8	19 55 58	326 11	−13 11	200 06	−15 40	9,6	32
39	1959 VI, 30	21 44±1	51 54	59 37	214 48	58 20	1,3	8
40	1959 VIII, 4	23 45 11	304 46	59 26	34 59	59 36	6,6	34
41	1959 VIII, 8	20 33 35	42 45	55 06	248 20	54 20	3,3	18
42	1959 VIII, 14	0 36 27	329 19	38 44	31 47	38 46	3,6	8
43	1959 VIII, 14	0 59 12	318 08	59 24	44 47	59 34	13,8	26

where

$$h_0 = r_0 \cos z_0 + \frac{r_0^2}{2\varrho_A}\sin^2 z_0 - \frac{z_0^3}{(2\varrho_A)^2}\sin z_0 \sin 2z_0;$$

$$h_1 = -\cos z_R + \frac{r_0}{\varrho_A}(\cos z_0 \cos z_R - \cos\psi_0); \qquad (10)$$

$$h_2 = \frac{1}{2\varrho_A}\sin^2 z_R; \quad \cos z_0 = a_0 \cos\varphi'_A + c_0 \sin\varphi'_A; \quad \Delta\varrho_j = \varrho_A - \varrho_j.$$

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The correction $\Delta\rho_j$ can be calculated by using the relationships

$$\varrho_A = \frac{a}{\sqrt{1+\varepsilon \sin^2 \varphi_A'}}; \qquad \varphi_j = \frac{a}{\sqrt{1+\varepsilon \sin^2 \varphi_j'}},$$

where

$$\varepsilon = \frac{a^2 - b^2}{b^2} = 0{,}0067385;$$

a and b are the major and minor semiaxes of the Krasovskiy Earth spheroid; φ_j' is the geocentric latitude of the j-th point.

TABLE 2.

V km/sec	$M_{ph\ max}$	H_1, км	H_2, км	sin Q	H_3, km	w_3, km/sec^2	H_4, km	w_4, km/sec^2	Remarks
52,2	$-3^m{,}8$	103,0	89,8	−0,559	—	—	—	—	—
28,0	−1 ,7	86,1	81,2	0,0975	—	—	—	—	—
31,9	−2 ,2	92,4	88,9	0,0334	—	—	—	—	Virginids
18,2	−2 ,2	85,6	83,4	−0,149	—	—	—	—	Boötes
58,0	−2 ,4	102,4	87,6	0,177	89,8	7	89,4	14	Perseids
22,0	−1 ,5	87,8	82,7	0,110	—	—	—	—	-
68,3	−3 ,7	97,1	90,5	0,395	94,4	37	91,9	213	-
60,1	−7,0 brighter	106,9	81,6	0,232	—	—	—	—	Perseids

Decomposing the expressions for ρ_A and ρ_j into series and limiting the first terms, since even the difference between the second terms cannot exceed 4m, we obtain

$$\Delta\varrho_j = \frac{a\varepsilon}{2}\left(\sin^2\varphi_j' - \sin^2\varphi_A'\right) = 21\,490\left(\sin^2\varphi_j' - \sin\varphi_A'\right) \text{ в } (м),$$

There remains the unknown geocentric latitude.

It can be determined from the figure thusly:

$$\sin^2\varphi_j' = \frac{(\bar{\varrho}_j + \bar{H}_j)^2_\xi}{(\bar{\varrho}_j + \bar{H}_j)^2},$$

where $(\bar{\varrho}_j + \bar{H}_j)_\xi$ is the projection of the given vector on the ξ axis. It is not difficult to show that

$$(\bar{\varrho}_j + H_j)^2_\xi = (\varrho_A \sin\varphi_A' + r_0\bar{\gamma}_{01} - L_j\gamma_R)^2,$$

$$(\bar{\varrho}_j + \bar{H}_j)^2 = \varrho_A^2 + r_0^2 + L_j^2 + 2\varrho_A r_0 \cos z_0 - 2\varrho_A L_j \cos z_R - 2r_0 L_j \cos\psi_0.$$

For calculation of φ_j' it is also possible to use the formula

$$\sin \varphi_j' = \frac{\varrho_A \sin \varphi_A' + r_0 \bar{\gamma}_{01} - L_j \gamma_R}{h_0 + h_1 L_j + h_2 L_j^2 + \varrho_A},$$

where h_0, h_1 and h_2 have the same value as in formulas (10). These coefficients are constant for the whole meteor, and therefore application of these formulas is especially suitable for determing the altitudes of a large number of points.

The velocity and deceleration were determined graphically. To do so, the moments of the intervals within one cycle were determined by interpolations, then the curves $L=L(\tau)$ were constructed, where τ is the time computed from the initial point on the meteor. After smoothing, graphic differentiation was used to obtain the curves

$$v = v(\tau) \text{ and } w = w(\tau).$$

Results of operation are given in table 2, where λ is angular length of the meteor in degrees; v_∞ is the preatmospheric velocity; $M_{ph\ max}$ is the maximum photographic brilliance; H_1 and H_2 are the altitudes of the appearance and disappearance; w_3 and w_4 are deceleration at the points whose altitudes are respectively H_3 and H_4.

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